L
42
F68
.1

DOT HS 801 600

Dept. Of Transportation
SEP 30 1975
Library

RESEARCH SAFETY VEHICLE (RSV) PHASE I FINAL REPORT- VOLUME I. INTRODUCTION, EXECUTIVE SUMMARY

Contract No. DOT-HS-4-00842
June 1975
Final Report

PREPARED FOR:
U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
WASHINGTON, D.C. 20590

Document is available to the public through
the National Technical Information Service,
Springfield, Virginia 22161

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

TL
242
.F68

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catolog No.
DOT HS-801 600 V.1		

4. Title and Subtitle	5. Report Date
Research Safety Vehicle (RSV) Phase I Final Report, ~~Volume I of Three Volumes~~ V.1 Introduction, Executive Summary	June 1975
	6. Performing Orgonization Code
	8. Performing Orgonization Report No.
7. Author(s)	
9. Performing Organization Nome and Address Ford Motor Company Environmental and Safety Research Office P. O. Box 2053 Dearborn, Michigan 48121	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DOT-HS-4-00842
12. Sponsoring Agency Name and Address Department of Transportation National Highway Traffic Safety Administration 400 Seventh Street S.W Washington D.C 20590	13. Type of Report and Period Covered FINAL REPORT January 1974- April 1975
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This is Volume I of three volumes - RSV Phase I Final Report

Vol. II -- Automobile Usage Trends, Accident Factors
Vol. III -- Vehicle Characterization, Performance Specifications

In response to the requirements of the Statement of Work an analytic approach was developed which:

- Predicts the accident exposure environment for the mid-1980's time period based on factors influencing automobile usage.
- Employs the principal elements of this prediction as input to a mathematical model which simulates the various types of accidents (front, side, etc.) occurring in that environment.
- Tests multiple combinations of RSV structural and restraint system configurations to determine that combination which predicts achievable safety performance, given practical constraints on size, weight, and cost.
- Evaluates the cost-benefits of various candidate configurations to select an optimized vehicle design concept for an RSV weighing less than 3,000 pounds which operates in the projected mid-80's traffic environment.
- Establishes recommended performance specifications for the optimized design concept.

17. Key Words	18. Distribution Statement
Safety vehicle, crashworthiness, accident data analysis, optimization of safety countermeasures, casualty reduction	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	26	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

	Page
VOLUME I -- Introduction, Executive Summary	
1.0 Introduction	1-1
2.0 Executive Summary	2-1
VOLUME II -- Automobile Usage Trends, Accident Factors	
3.0 Program Definition Foundation	3-1
3.1 Automobile Usage Trends	3-1
3.1.1 Factors Influencing Automobile Usage	3-1
3.1.1.1 Demographic Considerations	3-1
3.1.1.2 Impact of Alternate Transportation Modes	3-2
3.1.1.3 Roadway Development	3-4
3.1.1.4 Traffic Regulations	3-7
3.1.1.5 Economics	3-11
3.1.2 Vehicle Projections	3-11
3.1.2.1 Total Number of Vehicles	3-11
3.1.2.2 Car Distribution by Age	3-12
3.1.2.3 Vehicle Distribution by Weight	3-14
3.1.2.4 Total Vehicle Miles of Travel	3-18
3.1.3 Summary	3-20
3.2 Accident Factors (Data Sources/Data Analyses)	3-21
3.2.1 Vehicle Accident Exposure	3-21
3.2.1.1 Collision Types - Frequency of Occurrence	3-22
3.2.1.2 Accident Severity	3-38
3.2.1.3 Exposure Projections	3-67
3.2.2 Vehicle Occupants	3-71
3.2.2.1 Driver Age and Sex	3-71
3.2.2.2 Seating Position Occupancy	3-82
3.2.2.3 Occupant Size Distribution	3-90
3.2.3 Pedestrian Factors	3-91
3.2.3.1 Literature Review of Pedestrian Injury Studies	3-92
3.2.3.2 Roadway Environment Modifications	3-101
3.2.3.3 Pedestrian Factors Conclusion	3-104
3.2.4 Summary - Accident Factors	3-104
3.3 RSV Methodology	3-105

Page

VOLUME III -- Vehicle Characterization, Performance Specification

4.0 RSV Optimization System 4-1
4.1 Accident Exposure Projection 4-6
4.2 Vehicle Simulation 4-12
4.2.1 Structural Models 4-12
4.2.2 Functional Parameters 4-29
4.3 Occupant Simulation 4-30
4.3.1 Dynamics Model 4-30
4.3.2 Functional Parameters 4-48
4.4 Dynamics Model Approximations 4-50
4.4.1 Experiment Design Matrix Rationale 4-51
4.4.2 Vehicle Experiment Design and Regression Model Results 4-57
4.4.3 Occupant Dynamics Experiment Design and Regression Model Results 4-63
4.5 Biomechanical Model 4-87
4.6 Rollover Containment 4-100
4.7 Countermeasures Cost and Weight Data 4-108
4.8 Optimization Algorithms 4-121
4.9 Optimization System Model 4-125
4.10 Benefit-Cost Analysis Rationale 4-142
4.11 Summary of Assumptions 4-145
4.12 System Model Adjustment and Validation 4-147
5.0 RSV Characterization 5-1
5.1 Producibility Constraints 5-1
5.2 Vehicle Configuration 5-3
5.3 System Model Results 5-16
5.4 Benefit-Cost Analysis 5-18
5.5 RSV Functional Parameters 5-22
5.6 RSV Projected Performance 5-24

Page

VOLUME III -- Vehicle Characterization, Performance Specification (cont'd)

6.0 RSV Performance Description and Specification 6-1

6.1 Energy Management 6-1

6.1.1 Front Impact Barrier Crash Performance 6-1

6.1.2 Side Impact Moving Barrier Performance 6-13

6.2 Occupant Protection 6-20

6.2.1 Front Impact 6-20

6.2.2 Side Impact 6-24

6.3 Variability Considerations 6-25

6.4 Other Energy Management Specifications 6-29

6.5 Accident Avoidance 6-31

6.5.1 Braking Performance 6-31

6.5.2 Steering 6-31

6.5.3 Handling 6-33

6.5.4 Visibility 6-39

6.5.5 Lighting 6-45

6.6 Post-Crash Factors 6-46

6.6.1 Extrication 6-46

6.6.2 Fire 6-49

6.6.3 Submersion 6-50

6.7 Non-Safety Systems 6-51

6.7.1 Interior Package 6-51

6.7.2 Controls and Displays 6-54

6.7.3 Vehicle Performance 6-59

6.7.4 Other Considerations 6-63

APPENDICES

A -- Vehicle Simulation Experiment Designs, Response Data, and Regression Coefficients A-1

B -- Supplement to "Comments of Ford Motor Company on Analysis of Effects of Proposed Changes to Passenger Car Requirements of MVSS 208;" B-1

C -- Data Processing and Computational Programs C-1

D -- The Need for Additional Rollover Accident and Handling Research and a Recommended Program D-1

E -- Braking Performance E-1

F -- Ford Research on Field of View F-1

G -- Headlight Evaluation Model G-1

Section 1

INTRODUCTION

This is the first of three volumes which constitute Ford Motor Company's final report on Phase I of the Research Safety Vehicle (RSV) Contract (DOT-HS-4-00842). In response to the requirements of the Statement of Work an analytic approach was developed which:

- Predicts the accident exposure environment for mid-1980's time period based on factors influencing automobile usage.
- Employs the principal elements of this prediction as input to a mathematical model which simulates the various types of accidents (front, side, etc.,) occurring in that environment.
- Tests multiple combinations of RSV structural and restraint system configurations to determine that combination which predicts achievable safety performance, given practical constraints on size, weight, and cost.
- Evaluates the cost-benefits of various candidate configurations to select an optimized vehicle design concept for an RSV weighing less than 3,000 pounds which operates in the mid-80's traffic environment.
- Establishes recommended performance specifications for the optimized design concept.

In summary, the performance specifications recommended for the RSV have been derived from an analysis which has evaluated tradeoffs within the driver/vehicle/highway system conceived for the mid-80's.

To establish this mid-80's environment, projections -- based on factors influencing automobile usage -- are made for the distribution by weight of vehicles on the roadway, the number of accidents of each collision type, and the speed distribution of these accidents. This represents the accident exposure ambient with which the RSV will interact.

The process for maximizing safety for the RSV is largely design oriented: that is, variations in the basic design elements of the proposed vehicle are tried by simulation until that combination of variations is found which predicts the achievable safety performance -- constrained, however, with an envelope of vehicle characteristics defined by an image vehicle. The image vehicle is one in the Pinto/Maverick class having a weight range of 2,700 to 3,000 pounds. The upper limit of weight reflects the weight of the vehicle with the largest powertrain and greatest weight of optional equipment (radio, air conditioning, automatic transmission, etc.,) that about 50 percent of all customers are projected to order. The image vehicle -- as most U.S. cars -- includes the design capability of having various models (two-door, three-door, four-door, station wagon, etc.,) derived from the basic platform. The model used in this study is the three-door hatch back, projected to be a popular choice for cars in this weight class in the mid-80's. Thus, the basic image vehicle establishes the frame of reference around which RSV requirements are developed.

The safety related parameters of the RSV design are developed within the system model which integrates seven mathematical models -- described in detail in Volume III -- representing accident exposure, vehicle structural response, occupant response to front impact, occupant response to side impact, a biomechanical transformation (relating injury severity to probability of survival), an optimization process (which controls the overall model), and a benefit-cost analysis program.

To illustrate the methodology employed, assume that we wish to optimize structural and restraint system "functional parameters" (foreframe stiffness, crush length, side door bolster thickness, restraint system stiffness,etc.,) for a three-point belt system with 75 percent usage. The optimization process conducts about 100 comparative evaluations within the model as it varies these RSV parameters through a wide range -- constrained by a given limit on structural and restraint system cost (e.g., $100, $200, or $300) for that set of runs. The output is an optimized set of parameters based on minimizing the combination of fatalities and injuries in both the RSV and other vehicles encountered within the given cost constraint. The optimization process exercises some 1,000

combinations of speed, car weight, driver size, and impact mode (front, side, etc.,) of accidents involving the RSV with other cars or with fixed objects.

The various combinations of optimized functional parameters -- literally design descriptions of the RSV -- are then compared in an incremental cost-benefit analysis program which recommends a particular set of parameters at a particular cost as the final design.

The performance specifications for the RSV are then derived from the selected set of functional parameters by using these parameters as fixed input into the full system model at various impact speeds and recording the outputs from the frontal and side impact models. The performance parameters (e.g., HIC versus speed and chest g versus speed for front impact and side impact) are described in Sections 2.0 and 5.6.

These performance values are shown as a function of a range of barrier crash speeds since it will be shown that an optimized vehicle cannot be specified by limiting the test requirement to a single speed. Crash testing into a fixed barrier is reported as a performance criterion only because it is in common use at present and neither time nor funding were available to analyze alternate approaches to validation testing. Additional research effort should be directed at developing lower cost approaches to performance testing. Correlation of sled tests to real world crashes, for instance, for restraint system evaluation should receive greater emphasis.

The Executive Summary (Section 2.0) which follows describes program results in more detail.

Section 2

EXECUTIVE SUMMARY

The objective of the RSV optimization process was to identify that set of functional parameters which could be expected to result in a smaller number of traffic casualties -- summing the casualties in both the RSV and the other car in the accident -- than any other set of functional parameters. That approach identifies those functional parameters which result in the fewest total traffic casualties when summed across the entire range of accident exposure, in contrast to the alternative and more common approach of trying to find the vehicle specifications which optimize performance in a stereotyped crash test at some arbitrary speed.

The functional parameters which define the RSV specify the mechanical characteristics of the occupant restraints, the front end structure, and the side structure. Optimization was not extended to other aspects of vehicle crash impact such as rollover and fuel retention; it is assumed at least for purposes of Phase I that those would be set at the prevailing FMVSS. Likewise, specifications for accident avoidance features were set by independent means, not by tradeoff with occupant protection features.

Restraints

Two alternative solutions are presented, for both three-point belts (combined lap and shoulder belts) and air bags. Both types of restraints are effective, with an advantage for the belts, when used. The choice between them may be less dependent upon safety considerations -- at least in an ideal sense -- than on matters of public policy. Specifications for a three-point belt arrangement are included because it is a tried and effective restraint. A solution for air bags is also presented in order to allow for RSV compatibility with this possibility.

The air bag solution offers the advantage of minimum disturbance of the habit of neglecting self-protection, but at the penalty of substantial cost and some chance of malfunction. The belt solution, on the other hand, is a relatively low cost means of providing very good safety, but at

the penalty of having to substantially change the public's attitude toward deliberate self-protection. Belts have been a profound success in practice. Accident studies have shown their effectiveness. The lap belt alone has been shown to reduce fatalities by as much as 70 percent -- larger, even than we are able to reproduce in our simulations. Laboratory calibrations of real world crashes have suggested lifesaving capability reaching high up into the speed range. Of course, the effectiveness of belts depends on their being used. Thirteen countries, plus Puerto Rico, already have mandatory belt usage. In Australia, legislation has resulted in an average wearing rate of about 75 percent.

A factor which cannot be disregarded is that the air bag is very much an active device, complicated and inherently uncertain in its operation. It is a deployed mechanism which will have all the problems mechanism have always had, those of: functional uncertainty, failure proneness, and at this point in time very uncertain durability. Quite inadequate information exists about its functional assurance and durability. Belts, on the other hand, while requiring deliberate initial action by motorists, are essentially passive in their operation; they just sit there and work. While there is some sensing and discrimination in the inertia reel, its mechanism can be relatively simple and uncritical because false alarms are of no consequence, unlike the case for air bags where a false alarm can be very bad.

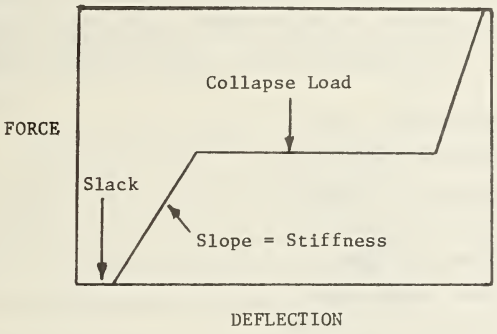
The RSV determinations in this analysis assumed that legislation would bring about a 75 percent wearing rate for three-point belts. For the air bag, considered as a quasi-passive restraint, the assumption was made of ten percent lap belt wearing rate.

The reasons for only ten percent lap belt wearing rate with the air bag stems from the following considerations. It is recognized that most people feel a natural negative valence toward belt wearing. Nevertheless, some people perceive the risk of injury to be large enough that it at least partially overcomes the negative reinforcement of belt wearing. As a result, there is at least a 30 percent voluntary wearing of the present three-point belt. For the rate to be any higher requires some positive incentive. If the incentive is mandatory use legislation, then the three-point belt wearing rate should go to 75 percent, as in Australia.

However, with air bags, it is expected that the incentive to seek extra protection will be substantially less because the risk will be perceived as considerably less. Furthermore, the substantial initial cost of the air bag will serve further to reinforce its subjective utility. As a result, it is believed only a small number of car occupants would bother to use the lap belt and that public opinion would undermine any attempt to require lap belt usage once air bags are in.

Parameter Description

The parameters varied in this study, both for the restraints and for structure, were of the following general form:



Restraints. Each of the restraints was simulated with a certain amount of slack in addition to having different possible values of stiffness. The belts did not have the constant-force phase shown above in their characteristic, but phased from the initial stiffness right into the bottomed-out condition. The air bag collapse load was not constant but had a 30 percent rising slope. The occupant bottomed-out in all cases into an assumed structural stiffness of 20,000 pounds per foot. The restraint parameters are listed below, the last two pertain to protection in side impacts:

1. Belt system stiffness
2. Steering column collapse load
3. Air bag collapse load

4. Air bag effectiveness time
5. Side bolster thickness
6. Side bolster collapse load

Front Structure. The front structure parameters are also described by the preceding figure, excepting that most of them had no initial slack. The characteristic shown is the *static* crush property; however, the simulation did provide for the dynamic case by a strain rate sensitivity parameter. The front structure is described in two main parts, the foreframe and aftframe. The foreframe is the front part of the frame, elevated to clear the front wheels and support the engine; the aftframe bends down toward the toe board and passes under the body, but only the part up to the firewall is considered part of the front structure. Crush length is the distance, including slack, from first contact to the bottom-out point in the preceding figure. The structural parameters varied in this study include these:

1. Foreframe force level
2. Foreframe stiffness
3. Foreframe crush length
4. Aftframe force level
5. Aftframe stiffness
6. Aftframe crush length
7. Sheetmetal force level
8. Sheetmetal stiffness
9. Sheetmetal crush length

Although these are the main parameters evaluated in the optimization process, many other variables entered into the calculations. For example, there were the masses for the suspension components, the bumper and the engine, and there were other deformable elements associated with them. Engine intrusion into the occupant compartment was another important calculation, with intrusion allowed on the assumption that any structure strong enough to completely constrain the engine would not be practical and that considerable intrusion could occur without injury. However a penalty was imputed to intrusion, in the form of a proportional likelihood of fatality resulting from it. The optimization process was designed to sense this along with other aspects of occupant response. Intrusion of

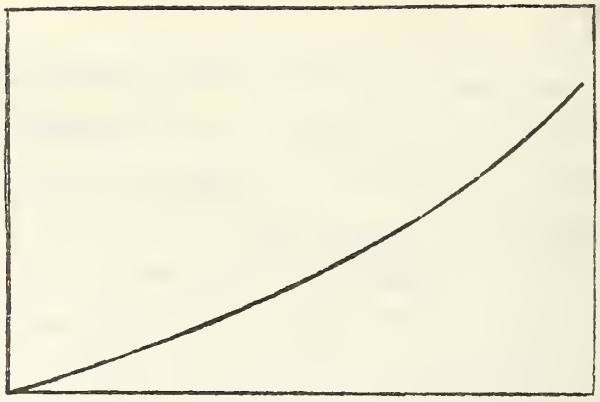
eight inches was considered inconsequential, in the posited geometry of the RSV occupant compartment, while intrusion of 18 inches was assumed to accompany so much vehicle deformation that chance of survival would be zero, regardless of restraints. The role of intrusion may be fairly influential as a determiner of optimization results, but the scope of the study did not allow a complete exploration of how intrusion affects the results. Therefore, this aspect of RSV definition should receive extensive study in the Phase II effort.

Side Structure. It was assumed in this analysis that the RSV would be struck in the side by vehicles representing the full range of those likely to be found in 1985 traffic, about a third of them being other RSV's. It was determined early that the principal means of occupant protection in side impacts was by providing an energy-absorbing restraint inside the vehicle, rather than in some kind of side superstructure.

It was observed that occupant response was relatively insensitive to a variation in side structure force level from 35,000 pounds to 70,000 pounds. Therefore, the image vehicle side structural force level of 35,000 pounds was held constant throughout the final optimization exercise. The side bolster thickness and force level were varied, however, and optimum values for them determined.

Crash Test Performance

The RSV functional parameters listed above are sufficient for establishing basic occupant protection requirements for the design of research vehicle. However, to place this RSV in a more familiar framework, the probable crash barrier performance of a vehicle with the optimal parameters was determined by simulating such crash tests with a vehicle-occupant-restraint model. The performance over the whole range of crash speeds was determined in that simulation, allowing performance at specific speeds, e.g., 30 mph or 40 mph, to be assessed by inspection of the summary curves. They are of the following form, and appear later, in the *Results*.



The System Model

The RSV optimization was determined through the use of a "system model," a collection of computer programs which, taken together, constituted: (a) the "exposure" -- a profile of accident events characteristic of the 1985 period, consisting of the statistical distributions of car weights and of impact speeds in each of the major crash modes as determined from current accident files, and the range of occupant sizes, (b) vehicle and occupant dynamic simulations, which produce calculated values of occupant deceleration for each of the exposure conditions, (c) an "optimization" program which searches among all the vehicle and occupant restraint parameter combinations for that set of parameters which yields the smallest measure of occupant injury when summed across all the possible conditions of exposure, and after allowing for weight-increasing parameter changes compensable by materials substitution within cost constraints, and (d) a cost-benefit analysis which relates the societal benefits in dollars to the incremental costs. Each of these major elements is further described below.

The exposure input to the system model is described by frequencies of collision, by impact mode and impact speed, as estimated for 1985. These are primarily based on current CPIR3 and towaway accident data. It is projected that 60 percent of the accidents will be vehicle-to-vehicle, the same as today, and that there would be about 1.2 million accidents producing disabling injuries, if long term trends of recent years persist.

The impact speed distributions projected for 1985 were based on accident data collected prior to the 55 mph speed limit; it was assumed that the curtailed speed limit will not remain in effect ten more years. The weight distribution of cars in 1985 was calculated on the premise of market forces, the number of small cars being predicted by taking into account a number of economic variables relating to such things as the prices of cars and of fuel. It is expected there will be over 115 million cars, of which more than 48 million will weigh less than 3,000 pounds. It was assumed for the calculation that all the cars in the 3,000 pound class in 1985 will be RSV's, or some 36 percent of the car population. That assumption does not mean we expect so early an introduction of RSV's that this 100 percent state could be reached by 1985; the assumption was made for the sake of convenient calculation. If vehicles of any weight class are equally likely to be involved in collisions with vehicles of any other weight class, eight percent of RSV involvements would be with other RSV's, and excepting for rear-enders, which were excluded, RSV's would be involved in an additional 23 percent of two-car accidents. Distributions were established for direct front-to-front collisions, for offset frontals, front-to-side, front-to-rear, and frontal pole and tree collisions.

Exposure conditions were summarized in 1,062 different collision categories, each one being some combination of collision mode, weight of each vehicle in the crash, impact speed, and occupant size. All these combinations taken together, and weighted for their proportional representation, make up the accident environment expected for 1985. Occupant injury was determined in this study for each of these 1,062 exposure conditions by calculations based on dynamic simulation.

This simulation was in two parts. The first of these, a simulation of the vehicle structure, determined the pattern of vehicle crash deceleration and occupant compartment intrusion for each of the 1,062 accident conditions defining the exposure environment. Each vehicle was represented in a structural simulation (developed by Battelle for the NHTSA ESV Program) by a set of masses interconnected by deformable members. The structural parameters are basically force-deflection characteristics of the structure, as listed previously. The simulation was referenced to a base vehicle, consisting of a set of parameters for a typical car in

the 3,000 pound class, mainly a Pinto/Maverick of today. Its functional parameters were the starting point in the optimization process and provide a frame of reference for comparison of the optimization results.

The second part of the dynamic simulation determined the accelerations experienced by the occupant for each variation in the restraint parameters, for each of the 1,062 types of collisions considered. The occupant's upper torso motion was simulated in frontal impacts by a single-mass model, which received an input based on the acceleration history produced by the Battelle structural model. In side impacts, a three-mass 3-D model developed by the University of Michigan was the basis for the determination of occupant acceleration. The output of the occupant response model, a time trace of acceleration, was converted into a fatality probability.

Three factors were considered as determining the likelihood of occupant fatality: chest acceleration, head acceleration, and the deformation of the forward compartment due to engine intrusion. Functions were established that relate the extent of each of those responses to the percent of fatalities among exposed occupants. The fatality probability implied a distribution of injuries of lesser levels, a function for which was defined in the system model. The resulting overall distribution was then converted into a single measure of casualty, the "equivalent fatality unit" (EFU), comprised of the number of fatalities plus a weighted sum of all injuries at each level.

The optimization algorithm used in this study searches among the vehicle-restraint parameter combinations to identify that set which minimizes the total number of fatalities and injuries, when summarized as EFUs, then sums the EFUs in the 1,062 combinations of collision exposure conditions after weighting each combination for proportional representation. By this means, the solution converges toward parameter combinations which result in the smallest number of casualties when looked at across the full exposure, even though the resulting set does not save as many lives as might be possible in any one crash mode. For example, saving lives as such at very high collision speeds might be subordinated by the calculation process if a more than compensating number of injuries (when measured in terms commensurate to fatalities by the EFU scale) can be saved at lower speeds by some other selection of parameters. Further, the transfer of

structure by the algorithm from one part of the car to another could cause an increase in casualties by impacts in the weakened area, but the optimization would opt for that if a more than compensating saving were realized in the other area. The optimization could call for additional weight in certain structural areas.

The addition of extra weight to achieve the structural properties called for by the optimization calculation requires that a corresponding amount of weight be subtracted by means of materials substitution somewhere in the vehicle. The amount of weight allowed to be transferred into energy management structure was limited to 140 pounds, that being the limit believed practical to achieve in a 3,000 pound car by substitution of lighter materials. The incremental weight was translated into an associated incremental cost.

Optimization calculations were made for different cost limits. All the solutions were then evaluated in a benefit-cost analysis program to determine the most acceptable one. The criterion for acceptable benefit relative to cost was that the incremental benefit divided by the incremental cost had to exceed unity. Thus, as the process of selection proceeded, successive system configurations were selected as being superior to those preceding in each case, only if the incremental benefit per cost exceeded unity. This is standard practice in such evaluations. Benefits were in dollar terms, $236,000 per life as developed from an NHTSA paper. Since injuries were scaled in commensurate terms, the same "value" was applied to each "equivalent fatality unit" (EFU). The optimal design concept, therefore, will have a total benefit in EFUs at $236,000 per EFU, and an associated total cost penalty: that due to restraint system, that due to the additional weight for structural upgrading and that for the light weight material substitued to compensate for the extra weight of the structure and the restraints.

Results of the Optimization

The optimization procedure resulted in a set of values for the functional parameters which characterize the RSV. Values are shown below for the RSV and also for the base vehicle. That set of parameters, in combination for both restraints and front structure, which results in the

minimum expected overall traffic casualties (both in the RSV vehicle and in the vehicles involved with it), while keeping the overall weight of the vehicle in the 2,700 to 3,000 pound region (but allowing for compensating tradeoffs in weight through use of lighter materials in less essential components of the vehicle) is described by the following functional parameters for the belt and air bag solutions respectively:

Belt Restraints

	RSV	Base Vehicle
. Belt system stiffness, pounds/foot	3650	4200
. Steering column collapse load, pounds	1035	1200
. Side bolster collapse load, pounds	650	--
. Side bolster thickness, inches	3.7	--

Air Bag Restraints

. Collapse load, pounds	4350	--
. Effectiveness time, milliseconds	40	--
. Side bolster collapse load, pounds	690	--
. Side bolster thickness, inches	2.8	

Structure. The structural forces are the constant force levels of the force-deflection characteristics (see figure on Page 2-3), and stiffness refers to the onset stiffness of the structure. The crush length is the *static* distance, including slack, from onset of contact to the bottom-out point. The structural parameters for the belt and air bag solution, and also for the 3,000 pound base vehicle follow:

	RSV		Base
	Belts	Air Bag	Vehicle
. Foreframe force, kip*	22.4	20.1	25.5
. Foreframe stiffness, kip/inch	17.2	13.5	13.5
. Foreframe crush inches	22.1	21.8	21.6
. Aftframe force, kip	23.2	25.4	25.0
. Aftframe stiffness, kip/inch	99.1	85.1	60.0
. Aftframe crush, inches	3.8	3.8	4.3
. Sheetmetal force, kip	3.1	2.7	3.0
. Sheetmetal stiffness, kip/inch	3.6	3.0	2.0
. Sheetmetal crush, inches	27.9	27.6	25.6

*kip = kilopound, 1,000 pounds

The preceding parameters represent the major structural factor affecting the "crash signature" -- the shape of the deceleration waveform -- of the projected RSV. In general, the projected parameters should produce a somewhat softer average front end than the base vehicle, particularly in the case of the projected air bag system. This means that the resulting *total vehicle dynamic crush* will be slightly larger than the baseline. Some implications of this increase in crush on the overall vehicle configuration are covered in Volume III of the Report. It is expected that the practical design process, during Phase II, will call for further exploration, through the optimization process, of other variables which affect front-end length, intrusion limits of powertrain components, etc., and thus of total crush.

Comparison Among Systems

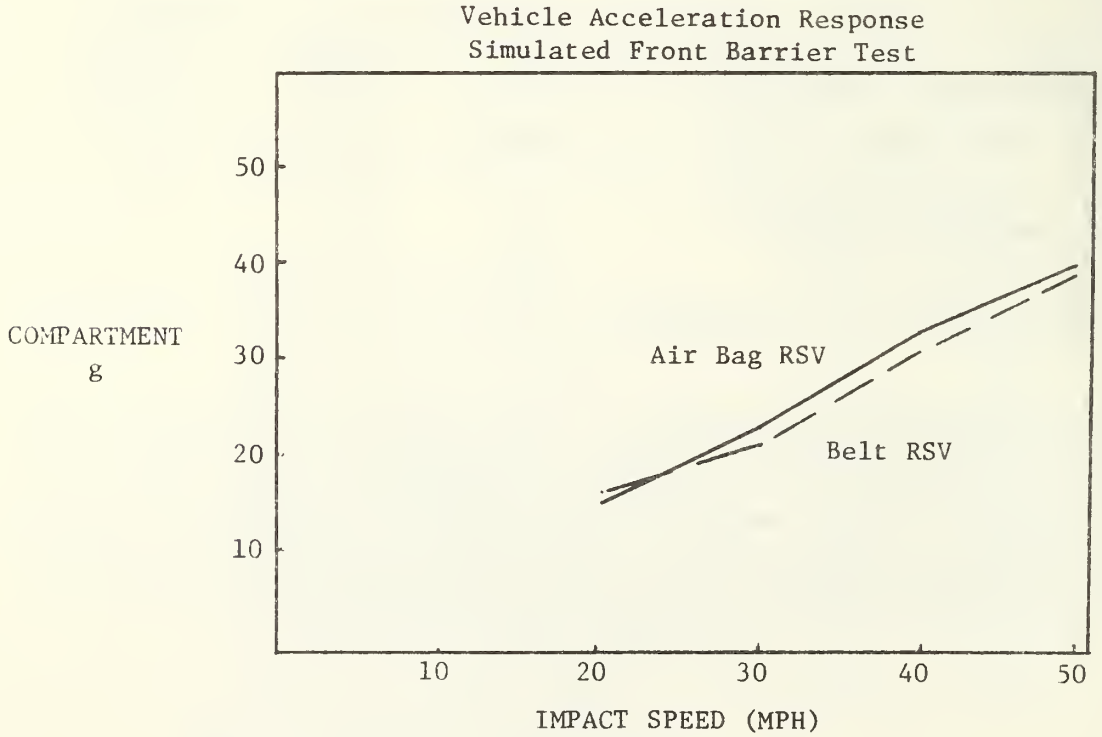
Taking the base condition as that for a 3,000 pound base vehicle similar to the current Pinto/Maverick operating in the 1985 environment, and assuming a 30 percent belt wearing rate, the solutions arrived at in this study produced the following estimates for the: casualty level in EFUs; savings; costs; benefit/cost ratios; and weight substitutions.

	RSV		Base
	Belts	Air Bag	Vehicle
. Wearing rate: RSV/Other*	75/75	10/30	30/30
. Equivalent fatality units	44,587	55,108	66,457
. EFU saved over base level	21,870	11,349	--
. Incremental cost over base	$60	$215	--
. Overall benefit/cost	16.8	2.4	--
. Weight substitution, pounds	13	6	--

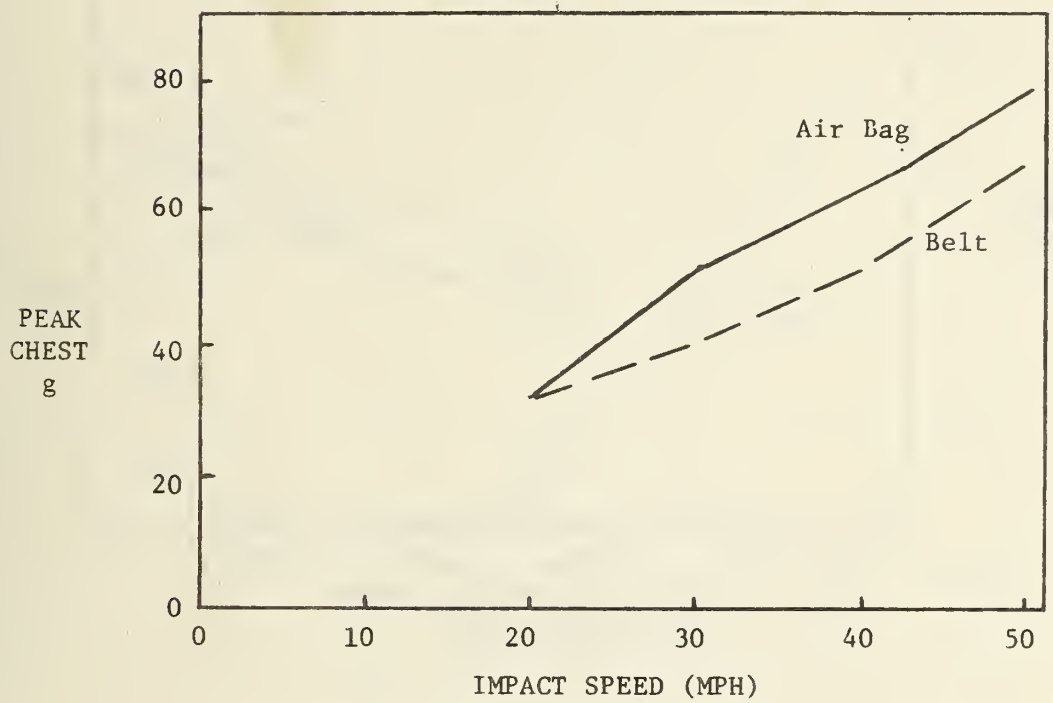
*For the *Belts* case, the assumption is that the RSV and all cars encountered by the RSV have a 75 percent belt wearing rate, the result of a mandated requirement. For *Air Bags*, the assumption is that the RSV has a ten percent lap belt wearing rate and that all non-RSV cars encountered have three-point belts with 30 percent usage. The *Base* car is in the 3,000 pound Pinto/Maverick class, and it is assumed that all cars, including it, have a 30 percent three-point wearing rate.

Crash Test Performance

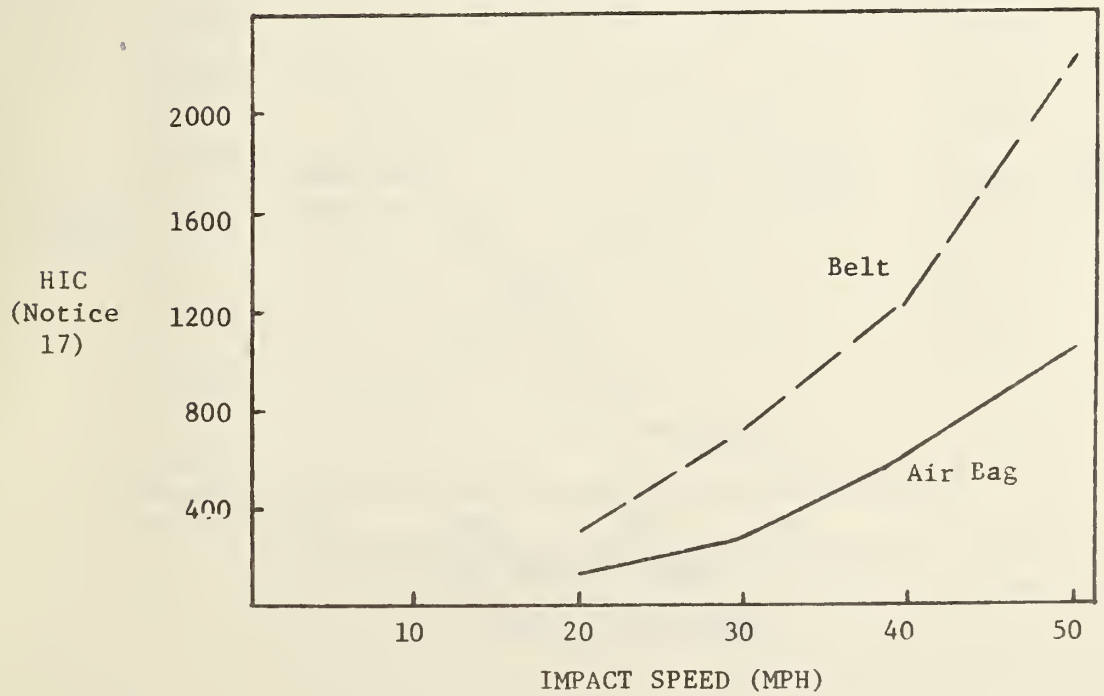
The RSV functional parameters listed above are sufficient for establishing the basic occupant protection requirements for the design of a research vehicle. However, to place this RSV in a more familiar framework, the predicted crash barrier performance of a vehicle with the optimal parameters was determined by simulating such crash tests. The simulation for frontal barrier tests used the Battelle structural model and the full 8-mass, 11-degree of freedom occupant model. The side impact tests used a Battelle-type simulation with a 4,000 pound movable barrier, and with the occupant simulated by a 3-mass, 3-D model. The simulation could not embody all possible variables which would affect response, so there will probably be a difference in what the model predicts -- which is necessarily an idealization -- compared to crash test results. Compartment acceleration and the expected occupant response -- nominal values for chest g, HIC and head g -- over the speed range of 20 to 50 mph, are shown in the graphs below, selected from a larger set in Volume III of the report. Two solutions -- RSV designed for belts and RSV designed for air bags -- are shown in each graph.



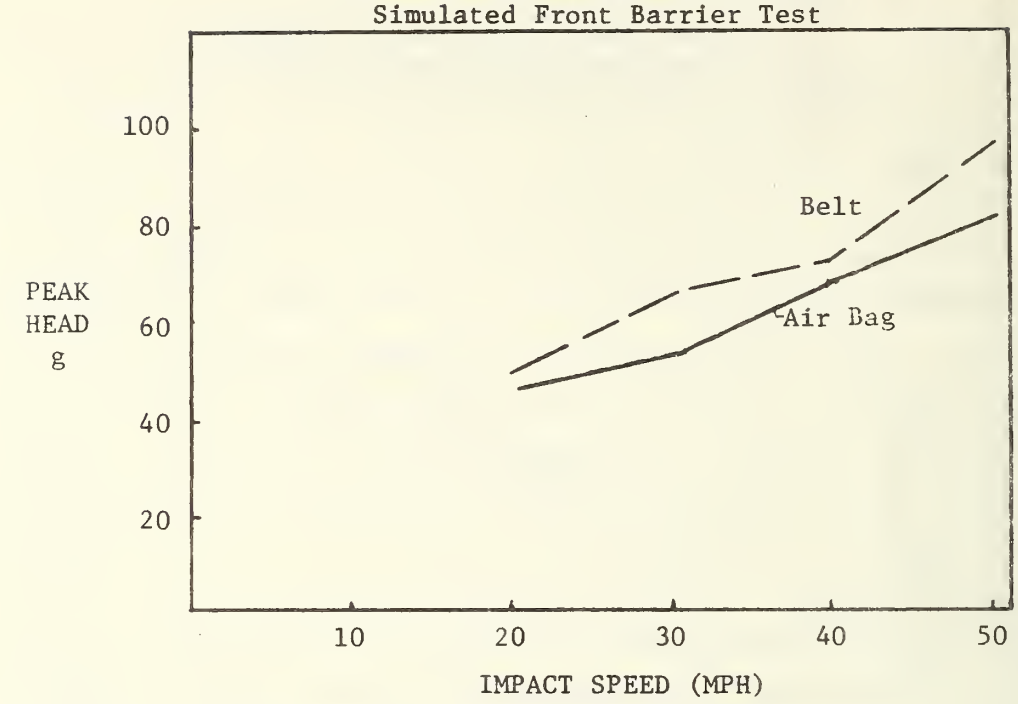
Driver Chest Acceleration Response
Simulated Front Barrier Test



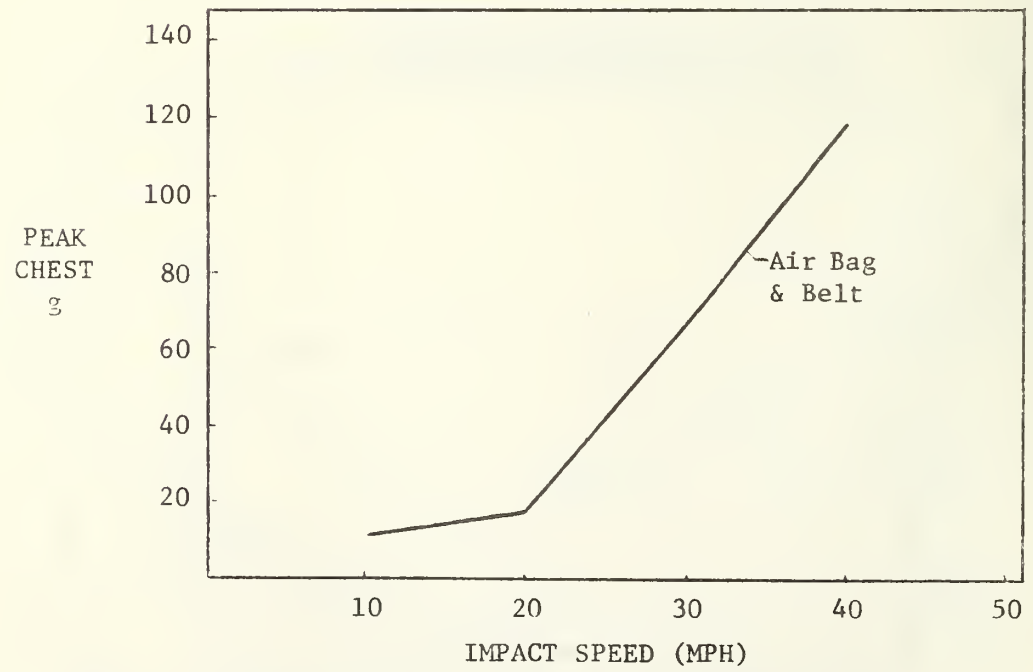
Driver HIC Response
Simulated Front Barrier Test



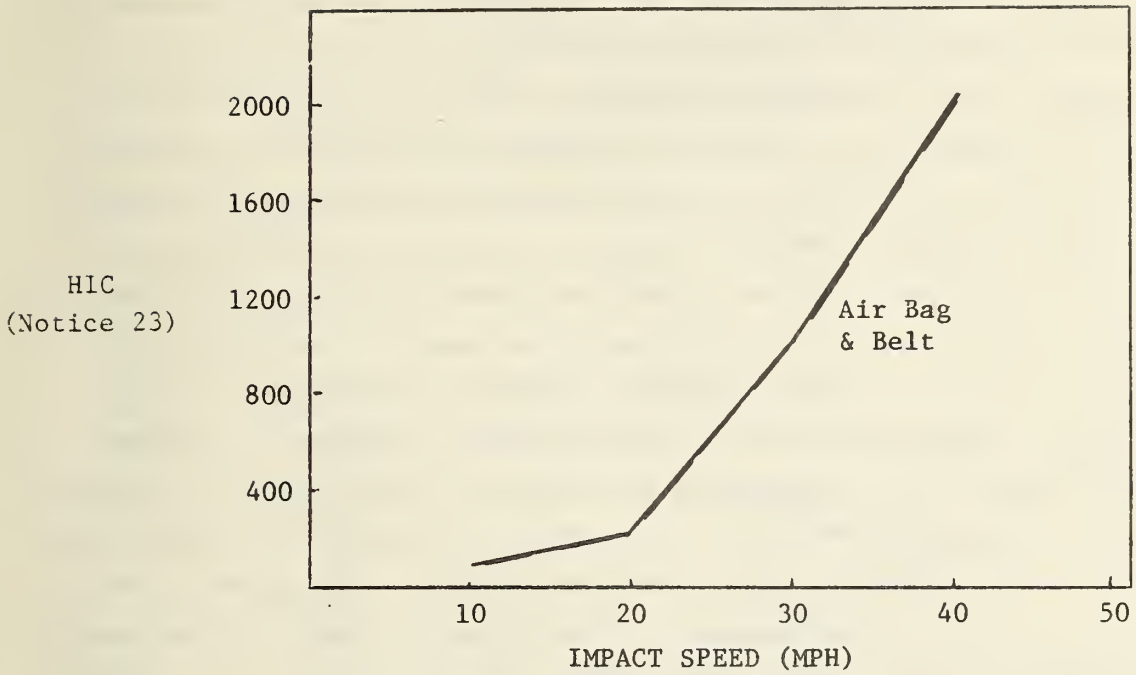
Driver Head Acceleration Response
Simulated Front Barrier Test



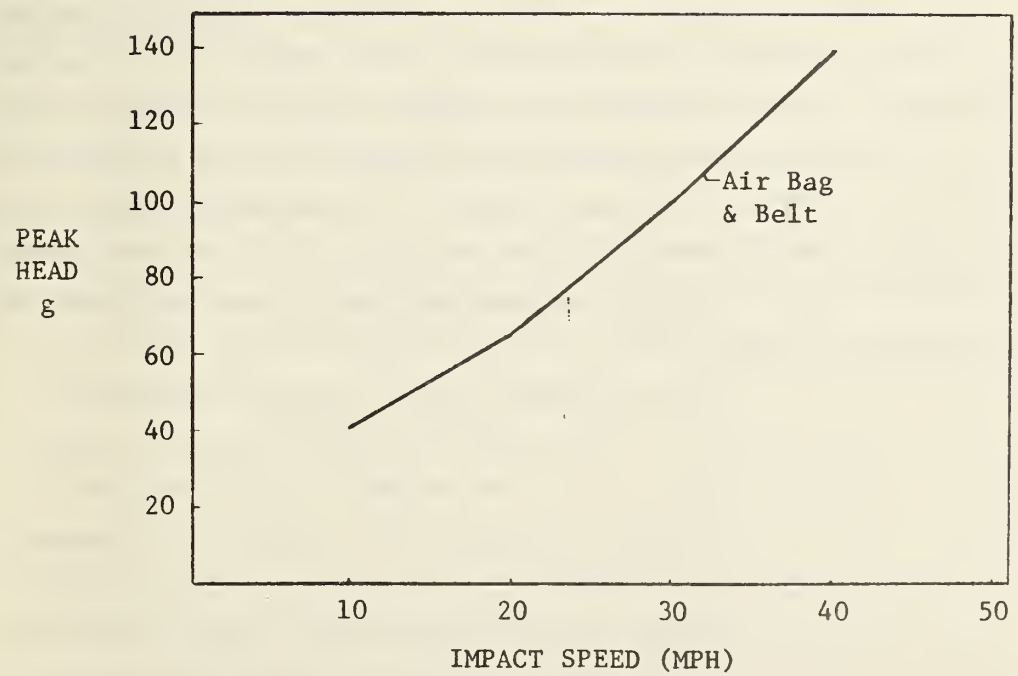
Driver Chest Acceleration Response
Simulated Side Moving Barrier Test



Driver HIC Response
Simulated Side Moving Barrier Test



Driver Head Acceleration Response
Simulated Side Moving Barrier Test

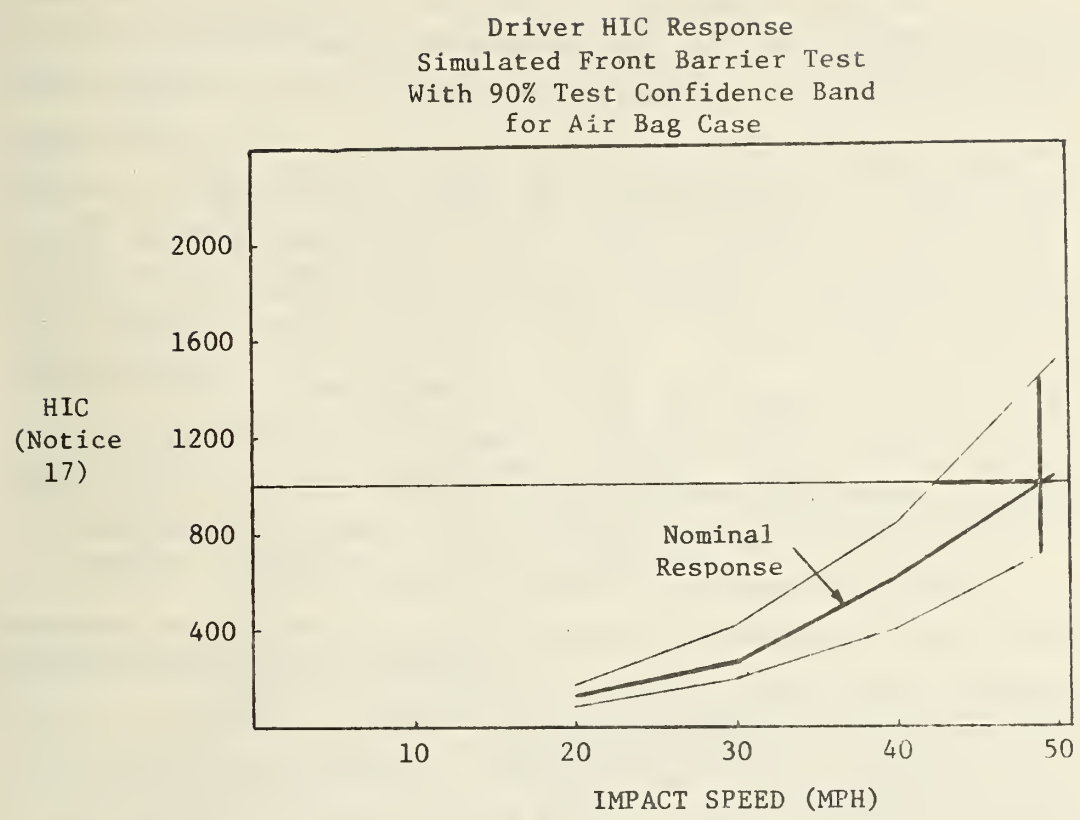


Test Variability Considerations

The calculations carried out in this study produce a nominal value for occupant response in barrier crash tests, as shown in the figures above. It is expected that when a vehicle is designed and constructed to conform to the functional parameters arrived at by the optimization process, that crash test results would be similar to the values shown in these figures. However, there is a source of uncertainty in crash test results over and beyond any discrepancy proceeding as a consequence of the necessary idealizations of the models. The additional uncertainty is due to chance variations arising in testing.

In a previous Ford Motor Company study, referenced in Volume III, 33 full size Mercury cars with air bags were crash tested to determine the amount of test variability. It was found that the results of any two identical tests differed by about 120 units in HIC, on the average, and by about 7 g in chest acceleration. The variability found in those tests was applied to the RSV optimization results, shown for HIC in the following figure, a repeat of the one shown previously. In this figure, the nominal results of the optimization are bracketed with the 90 percent confidence bands associated with chance variability occurring in individual crash tests.

The nominal response of 1,000 HIC occurs at a speed of 49 mph. Looking at the variability vertically, it is seen there is a 90 percent chance that the results of any one test could be in the range of 700 to 1460, and a five percent chance that it will exceed 1460. Looking at the variability horizontally, the lower limit of the uncertainty extends down to 42 mph, and to some indefinite value beyond the scale of computation in the upward direction. A more conservative band -- say for 99 percent -- would be quite a bit wider.



System Model Improvements

The system model for determining the optimum set of vehicle structure and restraint parameters contains a number of simplified approximations for the environmental inputs and for the simulations of vehicle and occupant dynamics. Even so, the scale of computation in the system model was very large. The system model went through the crash simulation for any given set of vehicle-restraint parameters 1,062 times, once for each of that many different exposure conditions, then summed the resulting 1,062 casualty figures (after weighting them for relative frequency) to yield an overall casualty sum, in EFU. The optimization process searched for that particular combination of the vehicle-restraint parameters which minimized the overall EFU sum, taking from 50 to 100 iterations to do so. Thus, there can be as many as 100 thousand determinations to be made for any single type of restraint. In this study, three different restraint possibilities were examined, and each of those were evaluated with two different cost constraints; thus, there were six restraint evaluations.

Since each of them took as many as 100 thousand determinations, the total number of determinations in the program were six times that many, or as many as some 600 thousand. It would be infeasible to run a Calspan-type multiple-mass occupant simulation that many times, the average cost being about $25 for each of those runs; nor was there time available in the RSV project to do them regardless of cost. Also, there would have to be as many as some 300 thousand Battelle structural model runs, which even at $10 each would be very costly. The 1,062 exposure conditions were a curtailed set; about ten times that many are provided for in the model and may have to be used in some exercises. Because of this prohibitively large number of cases, approximation methods were required in this study.

Various approximation approaches were taken. The Battelle structural response models were not exercised each time, but rather a few selected runs were made and an approximate relationship was determined for predicting deceleration history as a function of the structural parameter values by use of least-squares methods. That was also done for the 3-mass, 3-D occupant model in side impacts. An approximation based on least-squares procedures was also tried for an 8-mass occupant in the frontal collisions, but it could not reach a stage of adequate development during the Phase I period. Therefore, a single-mass occupant simulation was used for each run. However, the least-squares representation of occupant respone for the full 8-mass, 11-degree of freedom model is still under development and will be usable for Phase II. Considerable improvements in absolute accuracy can be made in the system model by further development.

The more accurate model will lead to a tighter confidence in the set of specifications. Furthermore, as a result of the total Phase I activity among all the contractors involved, some new considerations are likely to be brought up which would probably affect the optimization, and all these should be checked out by operation of the system model, preferably in its improved form.

During the design process of Phase II, unexpected limitations and/or new possibilities could emerge which would call for a departure from the set of parameters originally specified. The consequence of these practical changes, new constraints, and new possibilities should be

assessed thoroughly with the system model because these new considerations may lead to an optimization path that might not be obvious without a full analysis.

The new requirement for substantially increased fuel economy might have large implications for weight and material substitution, and as a result, a new optimization solution may have to be derived, once the design situation is clarified, in order to accommodate this new requirement.

The potential applicability of these methods to a simultaneous optimization of the whole range of vehicle types, not solely of a 3,000 pound RSV, would be a new and significant undertaking, requiring considerable adaptation of the system model.

Accident Avoidance Parameters

Models for relating accident occurrence to parameters of the vehicle control system are mainly speculative at this stage, and where some correlations are visible, they are not of sufficient analytical form to allow for the inclusion of accident avoidance tradeoffs in an overall system model which also includes factors for occupant protection. Occupant protection is conceptually simpler in that impact events are essentially ballistic, with consequences following causes in a relatively straightforward manner from the basic principles of mechanics. Accident avoidance, on the other hand, involves a complex feedback situation with the human operator in the loop. There are virtually no quantifiable data available which adequately describe this kind of situation -- thus accident avoidance parameters are not available for RSV optimization purposes. Therefore, only best estimates of performance needs and requirements are advanced in this study for brakes, steering, handling, field of view, lighting and signaling, interor package dimensioning, and for other performance considerations.

Braking. Braking performance of the RSV is to conform with FMVSS 105-75. However, there are major qulifications of the procedures that include a demonstration of testing accuracy, a tolerance based on pavement calibration, an alternative specification of braking effectiveness for both wet and dry conditions and according to locked wheel as opposed to peak-slip conditions.

Steering. A number of demonstration tests are described which will assure competitive adequacy in steering. Details are given on steering wheel returnability and vehicle steering recovery in defined maneuvers, backlash, turning diameter, and steering efforts.

Handling. In part, handling requirements are consistent with earlier ESV work. Two tests are drawn from the 3,000 pound ESV proposal, the steady state yaw response and the transient yaw response. These ESV handling specifications can serve as interim guidelines; however, they do not guarantee a vehicle which is both familiar to the ordinary driver and adequate in controllability and stability as empirically determined by vehicle development experts. Therefore, a number of evaluation tests, generally following the chassis tuning process currently used in automotive development are proposed as the principal criteria of RSV handling, with the result that RSV handling will, for the most part, reflect the probable state of the art for all vehicles of this size. These criteria include such things as evaluations for torque steer, power and brake hop, directional stability in various types of maneuvers and in various environments, and cornering performance on banked and unbanked curves. Handling and braking evolution of the RSV can be monitored by means of mathematical vehicle simulations until prototype hardware becomes available for field testing. Simulation models for this purpose were developed for NHTSA by Bendix Research Laboratories and Johns Hopkins University. This report includes a comprehensive outline of accident and handling research needed.

Driver Field of View. The driver field of view specified for the RSV will conform to the visibility standard proposed to NHTSA by Ford Motor Company in response to NHTSA dockets on that subject. The field of view specification is given in the form of visibility targets that must be visible to the driver, and provides for 360 degree coverage around the car, with assured visibility to the items of principal visual need. This will be accomplished with essentially conventional rear vision mirrors, but with considerably expanded fields of view, and with some reduction in the commonplace visual obstructions. Defog and defrost areas, sun visors, windshield transmission and shade bands, etc., will conform to FMVSS.

Lighting and Signaling. Headlighting, signaling and marking systems for the RSV will be the requirements specified in FMVSS 108 excepting that a separate stop signal will be provided.

Interior Package. Specifications are provided for basic interior dimensioning in order to satisfy ordinary requirements for comfort and convenience, for reach to controls, for foot and head clearance, etc. SAE standard detailing procedures for defining and measuring interior accommodation and visibility and legibility of instruments are specified.

Vehicle Image and Other Considerations

The Ford Phase I RSV Program effort also addresses the issue of developing vehicle specifications and a preliminary design concept that would be commercially acceptable and would be capable of being manufactured in a practical manner. To assure that the vehicle concept would be acceptable in the market place, a base RSV vehicle concept was established to reflect an image similar to current automobiles in the 3,000 pound range.

Vehicle "image" is a set of descriptions to convey only the broad impression of a new vehicle yet to be designed. Many of the image features are expressed in comparative quantitative terms relative to known, existing vehicles. The establishment of a weight limit in the 2,700 - 3,000 pound range (allowing for options), also establishes that the car will be in the Pinto to Maverick class, with seating capacity probably for four adults.

It should have the passenger carrying capacity, luggage space, fuel economy and fuel tank capacity and other customer functional features of currently acceptable vehicles approximating 3,000 pounds. Likewise, the price to the customer should also be competitive. To be commercially practical, the design must be adaptable to various models (two-door, three-door, four-door, station wagon, etc.) derived from the basic platform. The RSV design envisioned in this project is the three-door version, which is expected to be a popular model in this weight class in the future, and capable of accepting popular options. The RSV is expected to be about 180 inches overall, and about 100 inches wheelbase, with a unitized construction body.

It is expected that the RSV will be adaptable to at least two different engines, a four-cylinder in-line and a V-6, both of them with and without automatic transmission. The emission control and fuel economy

will be targeted toward the Phase II goals. The acceleration performance should be comparable to that of other Ford vehicles in the RSV class, emission and fuel consumption goals allowing.

It is expected that the vehicle will have both power steering and power brakes, and standard provisions will be made for heat/defrost/ventilation, rear window defroster, and an air conditioner with no less than standard capacity and cool-down power.

The RSV is expected to at least equal current vehicles in its size class in ride quality. Driveline and structural vibration, wheel impact harshness, and road, wind, drivetrain and equipment noise will also be at least as low as prevailing levels. It is expected that the RSV will be designed to meet the usual test track durability and reliability requirements of all Ford products, as will be the case for the in-service durability of items such as interior fabrics, scuff plates, exterior corrosion resistance, etc. Increased accessibility for servicing would also be a goal in the RSV.

A second aspect of producibility or practicality deals with designing for manufacturing, assembly, and supply feasibility. All design possibilities have been broadly reviewed for practical and feasible compatibility with known manufacturing and vehicle assembly capabilities. The RSV specifications are supported by design concepts that appear to be feasible in production, and could be the basis for guidelines for a practical-to-manufacture vehicle, with a reasonable expectancy of acceptance in the market place.

TL
242
.F68
V.1.

BORROWER

Form DOT F 1720
FORMERLY FORM DOT

DOT LIBRARY
00092231